The Conventional versus the Proposed Paradigm for Incremental Sampling of Soils at Military Ranges

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Conventional / Classic Incremental Sampling Design Paradigm (Strategy)

- Collect *n* = 1 incremental sample (IS) for each Sampling Unit (SU) & field triplicates for 10% of SUs.
- If %RSD < 30%, results fully usable. Otherwise, flag results (e.g., as estimated).
- %RSDs of SUs with triplicates "represent" precision of SUs for which *n* = 1.
- Decisions based on one IS result acceptable (e.g., maximum of SU is compared with a decision limit).

"Conventional" Approach

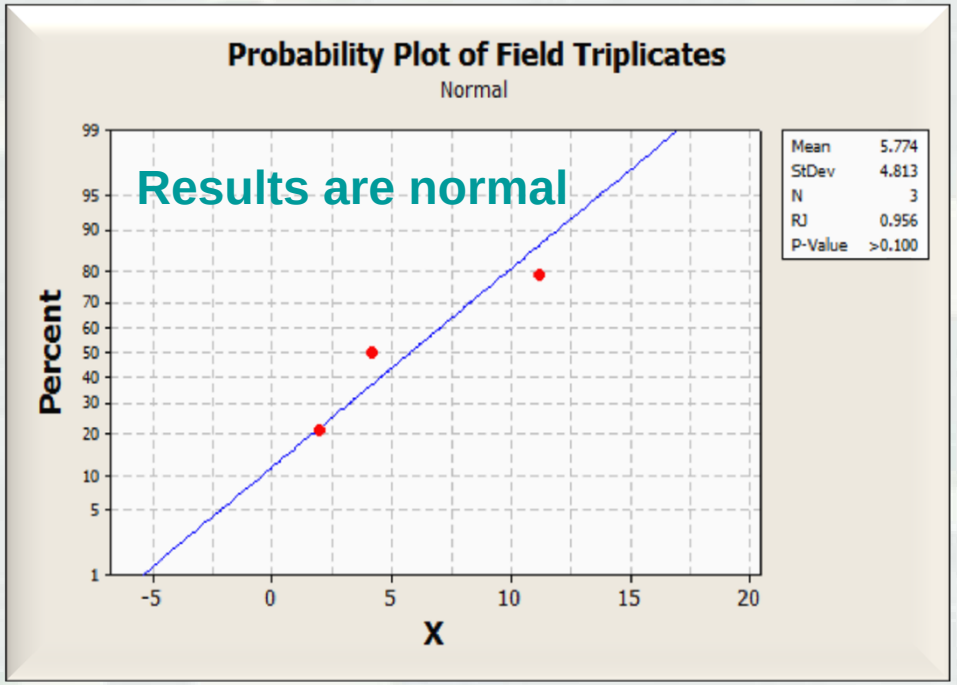
- Advantages: Cost effective and simple to understand and implement.

- Disadvantage: Data of unknown quality; ***decision errors*** are not controlled.

  - ***False positive (FP) error, α***
    (e.g., wrongly concluding
    site conc. > background/action level)
  - ***False negative (FN) error, β***
    (e.g., wrongly concluding
    site conc. ≤ background/action level)

Example of Classic Approach

- IS Field triplicates:
  - 4.2
  - 2.0
  - 11.2



Sample Statistics

$\bar{x} = 5.8, \; s = 4.8$

$\%RSD = (s / \bar{x}) \times 100$

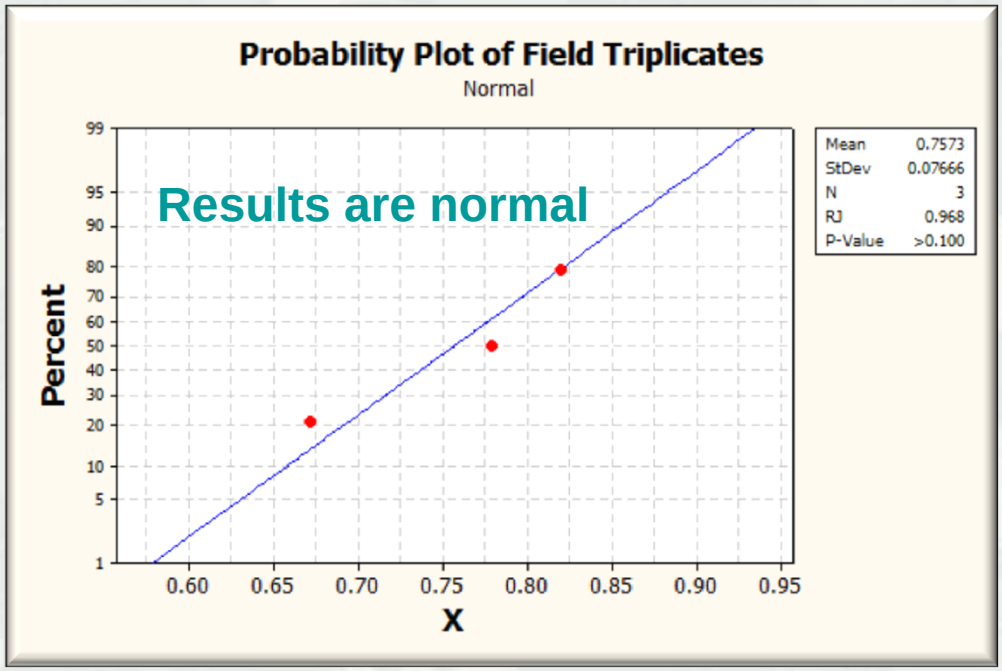
$= \mathbf{83\%} >> 30\%$

s = sample standard deviation

$\bar{x}$ = sample mean

Re-sampling of Triplicates

- Field triplicates:
  - 0.82
  - 0.67
  - 0.78

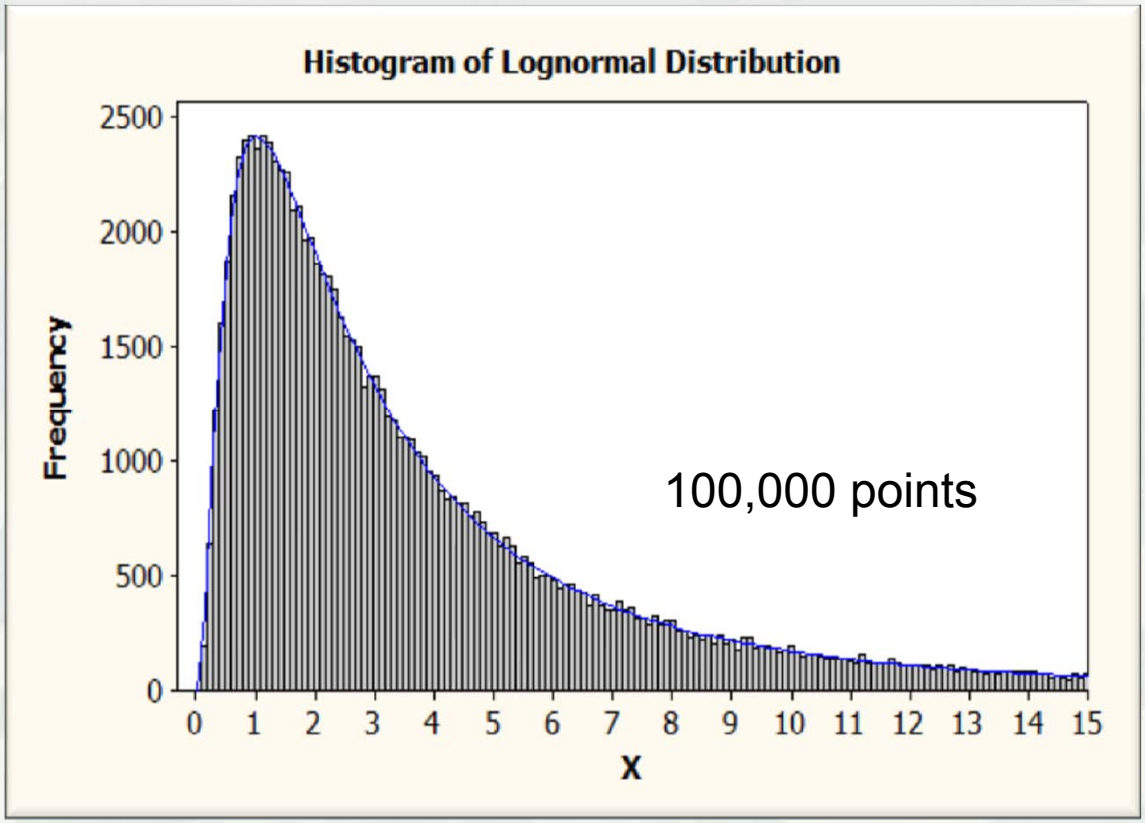


Sample Statistics

$\bar{x} = 0.76, \; s = 0.077$

%RSD = **10%** < 30%

- The two sets of triplicates were actually randomly selected from a lognormal distribution.



Population Parameters

$\mu \approx 4.5, \ \sigma \approx 5.9$

%RSD = 130%

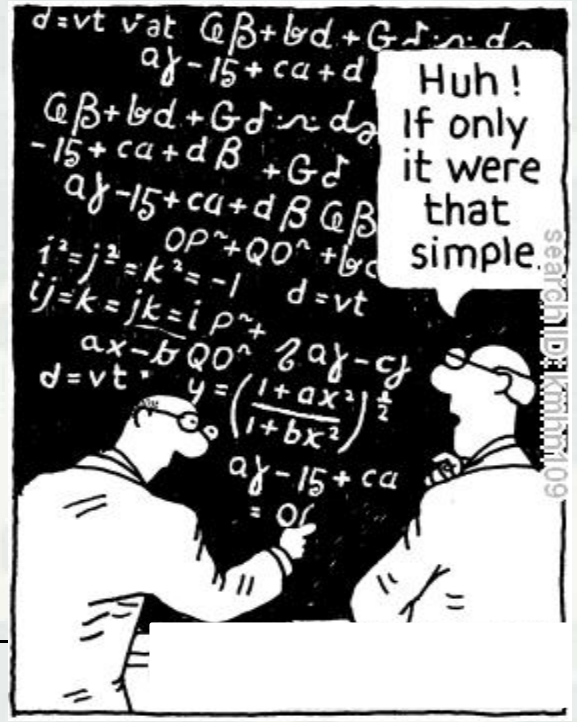
Sample %RSD	$\bar{x}$	95%UCL
83%	5 .8	14
10%	0.76	0.89

- Distribution cannot be reliably determined when *n* = 3.

ITRC Guidance Incremental Sampling Methodology (ISM) *

...the RSD does not provide an indication of the accuracy of the estimate of the mean or 95% UCL...

http://www.itrcweb.org/ISM-1/Executive_Summary.html



* ISM-1, Interstate Technology Regulatory Council, February 2012

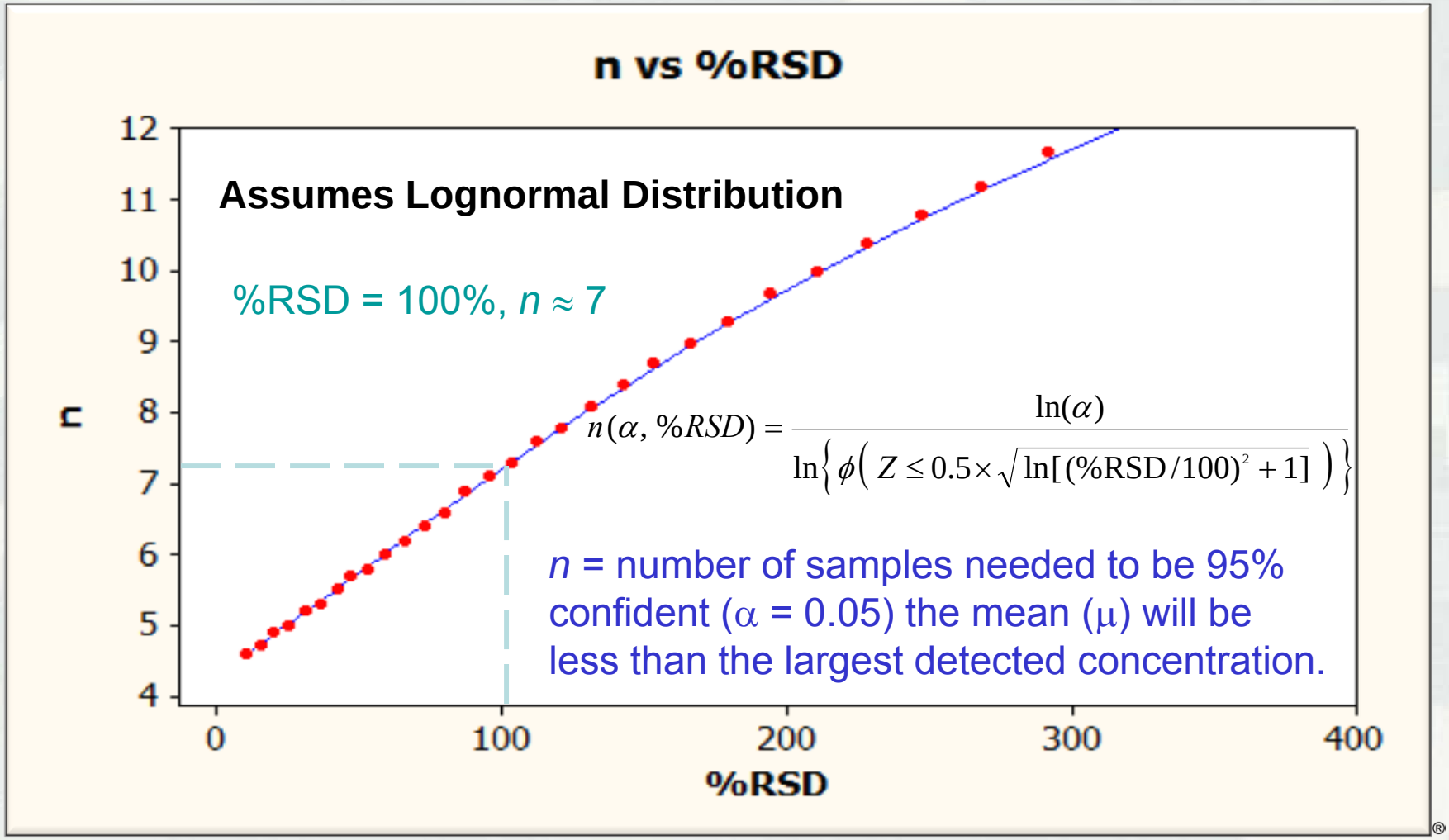
ITRC ISM Guidance

When a site includes many [Decision Units] DUs, it may be tempting to extrapolate the estimate of the variance (or the CV) [RSD] from one DU to another…

…Statistical theory suggests that we can expect the estimated mean and SD [standard deviation] to be independent for normal distributions but positively correlated for positively skewed distributions…If …independent,…high estimated means may have low SDs and vice versa…By contrast, if the parameters are correlated because of some asymmetry in the distribution…it would be preferable to extrapolate the average CV…A priori knowledge about the distribution shape is unlikely…

Translation: Don't extrapolate results; it doesn't work!

Comparing the maximum with an Action Level (AL)



Revised/Proposed Paradigm

- Use Data Quality Objective (DQO) or Technical Project Planning (TPP) Process.
- Determine replicates *n* for each SU using statistical approach (e.g., Visual Sampling Plan).

$$n \uparrow \rightarrow \alpha, \beta, (\Delta/\sigma) \downarrow$$

α = *FP error,* β = *FN error (e.g.,* $\alpha, \beta = 0.1 - 0.01$ *)*

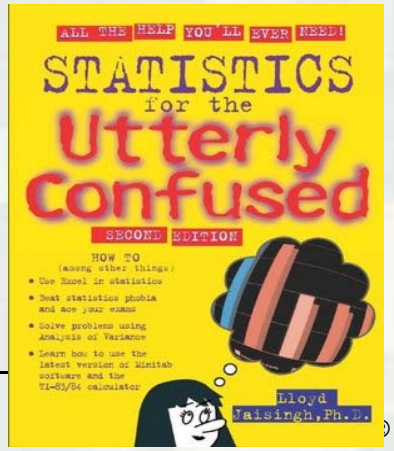
Δ = *Change important to detect (e.g.,* $\Delta = AL - \mu$*)*

σ = *Standard deviation* (Note: %RSD $\propto \sigma$)

- Use ***hypothesis tests*** to compare site means/medians with Action Level (AL) or background (BG) (e.g., using ProUCL).

  - USACE Engineer Manual (EM) 1110-1-1014, *Environmental Statistics* (Jan 2008).
  - EPA QA/G-9S, *Data Quality Assessment: Statistical Methods for Practitioners* (Feb 2006).

- Everything you wanted to know about hypothesis tests but were afraid to ask.



Alternatives to Hypothesis Tests

- Compare ***upper confidence limit (UCL)*** of mean with AL; conclude site is "clean" if UCL < AL.

$$\text{Student's t } 95\%\text{UCL} = \bar{x} + t_{n-1,0.95} \times s/\sqrt{n} \approx \bar{x} + (2-3) \times s/\sqrt{n}$$

(x is normal, $n \geq 3$)

$$\text{Chebyshev 95\% UCL} = \bar{x} + \sqrt{\left(\frac{1}{0.05} - 1\right)} \times s/\sqrt{n} \approx \bar{x} + 4\ s/\sqrt{n}$$

(x is not normal)

- Calculate (1-α)100% (e.g., 95%) BG ***upper prediction limit (UPL)*** to control FPs. SUs are consistent with BG if:

(Normality assumed)

$$\bar{x}_i < (1-\alpha)100\%\ \text{UPL}_{BG} = \bar{x}_{BG} + t_{1-(\alpha/k),n-1}\sqrt{\frac{1}{m}+\frac{1}{n}}\ s_{BG}$$

α	Site-wide FP error
n	Number of background samples ($n \geq 2$)
k	Number of site SUs ($k \geq 1$)
m	Number of (independent) replicates per SU ($m \geq 1$)
$\bar{x}_i$	Mean of m replicates for i^{th} SU, $i = 1, 2, \ldots, k$
$\bar{x}_{BG}$	BG mean
s_{BG}	BG standard deviation

BG sample maximum = γ 100% UPL (Non-parametric)

$\gamma = \gamma$ (n BG samples, k SUs, m replicates per SU)

$$\gamma = \left(\frac{n}{km+n}\right)\left\{\frac{\left(C_{m-1}^{m}\right)^{k}}{C_{km+n-1-k}^{km+n-1}} + C_1^k \frac{\left(C_{m-1}^{m}\right)^{k-1}}{C_{km+n-(k-1)}^{km+n-1}} + C_2^k \frac{\left(C_{m-1}^{m}\right)^{k-2}}{C_{km+n-(k-2)}^{km+n-1}} + \ldots + C_{k-1}^k \frac{C_{m-1}^{m}}{C_{km+n-2}^{km+n-1}} + 1\right\}$$

$$C_s^r = \frac{r!}{s!\,(r-s)!}, \quad s \le r$$

γ = Probability at least m-1 out of m replicates will be less than the maximum of n BG samples for each of the k SUs.

$\gamma \ge 0.9$		
	m = 2	**m = 3**
k	**n**	**n**
1	3	6
2	5	8
3	6	10
4	7	12
5	8	13

Gibbons, R. D, Some Additional Nonparametric Prediction Limits for Ground-Water Detection Monitoring at Waste Disposal Facilities, *Groundwater,* Vol. 29, No. 5 (Sep – Oct 1991)

Conventional Versus Proposed Approach

Approach	Conventional	Proposed
%RSD measures data quality	✓	×
Extrapolating %RSDs	✓	×
Decisions based one sample	✓	×
Statistical sampling design	×	✓

✓ Potentially acceptable
× Potentially unacceptable